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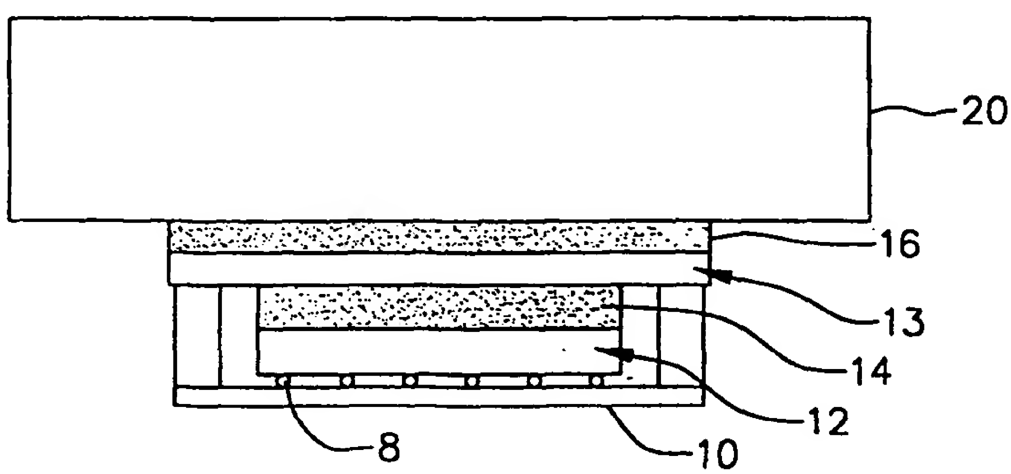

(57) Abstract

Described is an electronic device having a compliant fibrous interface. The interface comprises a free fiber tip structure having flocked thermally conductive fibers embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive and an encapsulant between the portionsof the fibers that extend out of the adhesive and the fiber's free tips.

ELECTRONIC DEVICE HAVING FIBROUS INTERFACE

BACKGROUND OF THE INVENTION

As electronic devices become smaller and operate at higher speeds, energy emitted in the form of heat increases dramatically. A popular practice in the industry is to use thermal grease, or grease-like materials, alone or on a carrier in such devices to transfer the excess heat dissipated across physical interfaces. However, the performance of these materials breaks down, e.g. deteriorates, when large deviations from surface planarity cause gaps to form between the mating surfaces in the semiconductor device or when large gaps between mating surfaces are present for other reasons, such as variation in package heights, manufacturing tolerances, etc. When the heat transfer ability of these materials breaks down, the performance of the device is adversely affected. The present invention provides semiconductor assemblies with fibrous interfaces that deal effectively with excess heat that may be dissipated in electronic devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a semiconductor assembly, with a heat sink to said in dissipation heat, and showing Level I and level II interfaces;

FIGS. 2A, 2B and 2C are schematic views showing flocked fibers in adhesive, pushed into the adhesive and resulting in more or less even fiber lengths extending from the adhesive; and

FIG. 3 is a schematic showing encapsulant between fibers and the free-fiber tips;

SUMMARY OF THE INVENTION

In one aspect of the invention there is provided an electronic device, e.g. a semiconductor assembly, that comprises a substrate, e.g. thermal spreader or lid, and semiconductor die with a fibrous interface, i.e. a free fiber tip structure, between the substrate and the die. The free fiber tip structure comprises flocked, e.g. electroflocked, mechanical flocked, pneumatic flocked, etc., thermally conductive fibers embedded at one end in a substrate, e.g. an adhesive, in substantially vertical orientation with portions of the fibers extending out of the adhesive. An encapsulant is disposed between the portions of the fibers that extend out of the adhesive. Disposing encapsulant material between the fibers minimizes or precludes fibers escaping the interface structure.

In other embodiments of the invention, an electronic device comprises a semiconductor assembly, e.g. a semiconductor assembly comprises a semiconductor package having a lid, e.g. a thermal lid or spreader, a semiconductor die disposed in the package and an interface comprising a free fiber tip structure between the semiconductor die and the lid of the package. The assembly may further comprise a heat sink and an interface between the lid of the package

and the heat sink. In both cases, the interface comprises flocked thermally conductive fibers embedded in an adhesive, as described above.

Another aspect of the invention is a method of making an electronic device. In the method, thermally conductive fibers of desired length are provided and, if necessary, cleaned. An adhesive is applied to a substrate and the fibers at one end are flocked to a substrate so as to embed the fibers into the adhesive with a portion of the fibers extending out of the adhesive. The adhesive is then cured and space between the fibers is filled with curable encapsulant. The fibers in the adhesive with the encapsulant in the spaces between the fibers is compressed to a height less than the nominal fiber length and clamped at the compressed height. Thereafter, the encapsulant is cured while under compression to yield a free-fiber tip structure with the fiber tips extending out of the adhesive and encapsulant (alternatively, the adhesive and encapsulant may be cured concurrently, as hereafter discussed.)

DETAILED DESCRIPTION OF THE INVENTION

Semiconductor dies are generally mounted within a package and the package is interfaced with an external heat dissipating device to draw away the thermal energy. A thermal interface between the semiconductor die and the package and/or a thermal interface between the package and the heat dissipating device, are useful for removal of heat so as to maintain optimum performance of the device. The interface between the semiconductor die and the package is referred to as "Level I" packaging or interface. The connection to the external heat dissipating device, such as a heat sink, is referred to as "Level II" packaging. This arrangement is shown in FIG. 1 which illustrates a semiconductor assembly with a package 10 within which encloses a semiconductor die 12 and which includes a thermal or spreader lid 13. A Level I interface 14 is in place between the semiconductor die and the lid and a Level II interface 16 is between the lid and the heat sink 20. The semiconductor device may be attached to the package by solder 8, as shown, and the lid may comprise a thermal lid or spreader, depending upon the particular electronic device involved.

The requirement for Level I and Level II interfaces are more stringent than other system level interfaces because the heat fluxes, i.e. power or heat dissipated per unit area, are higher. Reduction in thermal performance, typically expressed by an increase in thermal resistance ($^\circ C\ in^2/W$) may be accompanied by increase in device temperature for these interfaces.

An interface material for these applications advantageously possesses a low bulk thermal resistance and a low contact resistance. A suitable material is one that conforms to the mating surfaces, e.g. wets the surfaces. The bulk thermal resistance can be expressed as a function of the material's thickness, thermal conductivity and area. The contact resistance is a measure of how well a material is able to make contact with a mating surface. This thermal resistance of an interface can be written as follows:

$$\Theta_{interface} = \frac{t}{kA} + 2\,\Theta_{contact}$$

where Θ is thermal resistance
t is material thickness
k is thermal conductivity of material
A is area of interface

The term $\frac{t}{kA}$ represents the thermal resistance of the bulk material and $2\,\Theta_{contact}$ reflects thermal contact resistance at the two surfaces.

A good interface material should have low bulk resistance and low contact resistance, i.e. at the semiconductor die, thermal spreader, lid or heat sink surface.

Packages with Level I and Level II interfaces require that the interface material accommodate deviations from surface flatness resulting from manufacturing, and/or warpage of components due to coefficient of thermal expansion (CTE) mismatches.

In a Level I application, variation in the height of a cavity on a thermal lid leads to variation in interface thickness. A material with a low value for k, such as a thermal grease, would perform well if the interface is thin, i.e. t is low. If the interface thickness increases by as little as 0.002 inches, the thermal performance can drop dramatically. Also, for such applications, the difference in CTE between the semiconductor die, i.e. a silicon chip, and the thermal lid causes this gap to expand and contract with each temperature or power cycle. This variation of the interface thickness can cause pumping of fluid interface materials (such as grease) away from the interface.

Level II interfaces typically have a larger area and thus are more prone to deviations from surface planarity as manufactured. To optimize thermal performance, the interface material must be able to conform to non-planar surfaces and thereby lower contact resistance.

Optimal interface materials possess a high thermal conductivity and a high mechanical compliance, e.g. will yield elastically when force is applied. High thermal conductivity reduces the first term of Equation 1 while high mechanical compliance reduces the second term. An aligned thermally conductive fibrous material can accomplish both of these goals. Properly oriented, the thermally conductive fibers will span the distance between the mating surfaces thereby allowing a continuous high conductivity path from one surface to the other. If the fiber is flexible enough and able to move in its tip region, better contact can be made with the surface. This will result in an excellent degree of surface contact and will minimize the contact resistance of the interface material. A properly formed interface can be incorporated into one or more packaging components to form a thermal interface in Level I and/or Level II applications.

A semiconductor package may be constructed such that the interface material is applied to the cavity of the thermal lid between the lid and the semiconductor die. The lid can be

installed upon the semiconductor package so that the interface material makes contact with and is slightly compressed by the semiconductor die. In this arrangement, the lid is held in place while an adhesive between the lid and package is cured. The interface material is then able to accommodate variations in cavity height from part-to-part and changes in distance between the semiconductor die and the lid surface during thermal cycling.

To distribute or allow external heat dissipation, an interface material can be applied between the lid and an external heat dissipating device such as a heat sink. The interface material then accommodates manufacturing induced deviations from planarity from both the package and heat dissipating surface component. The interface material may be applied to either the heat dissipating surface, e.g. heat sink, heat pipe, heat plate, thermoelectric cooler, etc. or to the package surface. The heat dissipating device may be attached to the package through the use of spring clips, bolts, or adhesive, etc. in any conventional manner.

The interface material may be made as follows:

Suitable thermally conductive fibers such as diamond fibers, carbon fibers, graphite fibers, metal fibers, e.g. copper fibers and aluminum fibers, are cut to length, e.g. from about 0.0005 to 0.25 inches, preferably about 0.015 to about 0.250 inches, and having a diameter greater than about 3 microns up to 100 microns. Presently, fibers of about 10 microns diameter are preferred. Desirable fibers have a thermal conductivity greater than about 25 W/mK. Fibers of the type that are useful include those available Amoco identified as K-1100, K-800, P-120, P-100, P-70 and T50; as well as fibers available from Toray designated M46J and M46JB.

The fibers are cleaned, if necessary. Cleaning the fibers tends to remove any coatings present on the fibers. Some commercially available fibers are sold with a coating applied to the surface which is preferably removed by cleaning. One method of cleaning is by heating the fibers in air to burn off the coating, i.e. sizing. However, chemical cleaning methods can be also used.

To produce an interface, first adhesive is applied to a substrate. Advantageously, the adhesive is a low stress adhesive, for example, an adhesive comprising epoxy (e.g. Eccobond 281 from Grace Specialty Polymers) although cyanate ester adhesive, BMI, silicones, organosilicones, gels and spray gasket materials are also useful.

The fibers are flocked to the substrate, thereby embedding the fibers in the adhesive, as shown in FIG. 2A, for example by electroflocking. Electroflocking is a well known procedure whereby two plates, separated some distance, are charged to opposite polarity. The procedure is described generically by Bolgen (Bolgen Stig W., "Flocking Technology", Journal of Coated Fabrics, Volume 21, page 123, 1991) and specifically for electroflocking of carbon Fibers by Shigematsu in "Application of Electrostatic Flocking to Thermal Control Coating", Proceedings of the 14th International Symposium on Space Technology and Science, 1984, page 583; and by Kato in "Formation of a Very Low-reflectance Surface by Electrostatic Flocking", Proceedings of the 4th European Symposium on Space Environmental and Control Systems, 1991, page 565.

The disclosure of these articles is expressly incorporated herein by reference.

In the electroflocking process, fibers on one plate pick up that plate's charge and become attracted to the opposite plate. They embed in the adhesive when they hit the opposite plate. If they do not stick initially, fibers bounce back and forth between plates until they become embedded in the adhesive or escape the electric field or the charge on the plates is removed. The fiber structure that results is aligned with respect to the electric field lines, i.e. has a substantially vertical orientation, and has a velvet-like appearance.

Mechanical flocking involves passing an adhesive coated object over a series of rapidly rotating rollers or beater bars, which cause the substrate to vibrate. Fibers are fed onto the substrate by gravity from a hopper. The vibrations produced by the rollers or beater bars orient the fibers and drive them into the adhesive. Excess fiber is removed, leaving a fiber structure with substantially vertical orientation.

Pneumatic flocking uses an airstream to deliver fibers to an adhesive coated surface. While in flight, fibers align themselves in the direction of the airflow and embed in the adhesive in an oriented manner.

Different flocking methods may be used alone, or in conjunction with one another, e.g., pneumatic/electrostatic flocking. With this combination method, an airstream containing fibers is directed through a nozzle. At the exit of the nozzle, a charge orients the fibers with respect to electric field lines. The fiber structure that results is also aligned, i.e., has substantial vertical orientation, but may be denser, more uniform or produced more rapidly than when either method is used alone.

The flocked fibers are seated into the adhesive with a portion of their lengths extending from the adhesive layer, referred to as "free fiber tips". After flocking, a downward force is applied to the free fiber tips to seat the fibers in the adhesive and minimize the distance between the fiber tips embedded in the adhesive and the surface substrate to which the adhesive is applied, as shown in FIGS. 2B and 2C.

The adhesive is then cured, e.g. by self-curing or application of heat. Oftentimes heating for about 30 minutes at about 175° C may be used for curing, depending on the adhesive and curing conditions.

As shown in FIG. 3, an encapsulant, 30, for example a gel such as GE RTV6166 dielectric gel available from General Electric Corporation is introduced to fill space between fibers 32 leaving free fiber tips 34 extending from the gel. This can be done by stenciling uncured gel onto the fibers or applying the gel to the fibers and letting the gel soak or wick in. It is advantageous to use a gel that spontaneously wets the fibers and will wick into the fiber structure. The gel may or may not include a thermally conductive filler material. A release liner, i.e. waxy or silicone coated paper may be placed on top of the fibers and uncured gel to prevent the cured gel/fiber material from sticking to a clamping fixture and provides protection to the interface material during shipping or subsequent handling.

The interface with uncured gel between the fibers is compressed to less than the nominal cut fiber length and clamped in place to this compressed height. For example, if the fiber is about 0.02 inches long, adhesive cured gel is introduced then clamped to a height of about 0.017 inches before curing the gel which holds the fiber at this height while the gel is cured.

The gel is then cured, e.g. thermally cured, while under compression. Heating generally accelerates curing and is desirable to create a beneficial free-fiber tip structure. Both the compression and thermal cure aid in creating the free-fiber tip structure. The thermal cure is beneficial since the CTE of the gel is higher than that of the fibers and the gel will shrink more than the fibers upon cooling to room temperature, thereby exposing more fiber tips.

In producing the interface material, the adhesive curing may be delayed to coincide with the curing of the gel. In this case, the fibers are seated at the same time as the gel and the adhesive are cured. As indicated, compression is beneficial, and curing under compression is beneficial, because the gel will maintain the cured thickness and the fibers can spring back somewhat to stick up from the gel. Cohesion of the gel to the fibers is not strong enough to keep the fibers from assuming their original position prior to curing. This results in the free fiber tips which are desirable for enhanced thermal contact with the adjacent surface(s) and Level I and Level II applications.

It is apparent from the foregoing that various changes and modifications may be made without departing from the invention. Accordingly, the scope of the invention should be limited only by the appended claims, wherein:

WHAT IS CLAIMED IS:

1. In an electronic device comprising a substrate and a semiconductor die, the improvement comprising a compliant fibrous interface, said interface comprising a free fiber tip structure between the substrate and semiconductor die, said free fiber tip structure comprising flocked thermally conductive fibers embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive and encapsulant disposed between the portions of the fibers that extend out of the adhesive and beneath the free tips of the fibers.

2. The improvement according to claim 1 wherein the fibers comprise one of the group comprising carbon, graphite, metal, ceramic and diamond.

3. The improvement according to claim 1 wherein said fibers comprise carbon fibers.

4. The improvement according to claim 1 wherein said fibers have a length of about 0.0005 to 0.25 inches and a diameter from greater than about 3 microns up to about 100 microns.

5. The improvement according to claim 1 wherein the encapsulant is selected from the group comprising gels, such as silicone gels, and spray gasket materials.

6. The improvement according to claim 1 wherein the fibers comprise a material having a thermal conductivity greater than about 25 W/mK.

7. A semiconductor assembly comprising a semiconductor package having a lid, a semiconductor die disposed in the package, an interface comprising a free fiber tip structure between the semiconductor die and the lid of the package, said free fiber tip structure comprising flocked thermally conductive fibers embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive and encapsulant disposed between the portions of the fibers that extend out of the adhesive beneath the free tips of the fibers.

8. A semiconductor assembly according to claim 7 wherein the fibers comprise one of carbon fibers, graphite fibers, metal fibers, ceramic fibers and diamond fibers.

9. A semiconductor assembly according to claim 7 wherein said fibers have a length of about 0.0005 to 0.25 inches and a diameter from greater than about 3 microns up to about 100 microns.

10. A semiconductor assembly according to claim 7 wherein the encapsulant is selected

from the group comprising gels, such as silicone gels, and spray gasket materials.

11. A semiconductor assembly comprising a semiconductor package having a lid; a semiconductor die disposed in the package; a first interface comprising a free fiber tip structure between the semiconductor die and the lid of the package, said free fiber tip structure comprising flocked thermally conductive fibers embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive and encapsulant disposed between the portions of the fibers that extend out of the adhesive and beneath free tips of the fibers; a heat sink; a second interface comprising a free fiber tip structure between the lid of the package and the heat sink, said second free fiber tip structure comprising flocked thermally conductive fibers embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive and encapsulant disposed between the portions of the fibers that extend out of the adhesive and beneath free tips of the fibers.

12. A semiconductor assembly according to claim 7 wherein said fibers have a length of about 0.0005 to 0.25 inches and a diameter greater than about 3 microns up to about 100 microns.

13. A semiconductor assembly according to claim 11 wherein the fibers comprise one of carbon fibers, graphite fibers, ceramic fibers, metal fibers and diamond fibers.

14. A semiconductor assembly according to claim 11 wherein said encapsulant for the first and second interfaces comprises at least one of gels, such as silicone gels, and spray gasket materials.

15. A combination suitable for use in an electronic device comprising a heat sink and an interface comprising a free fiber tip structure, said free fiber tip structure comprising flocked thermally conductive fibers embedded in a substrate in substantially vertical orientation with portions of the fibers extending out of the substrate and encapsulant disposed between the portions of the fibers that extend out of the substrate and beneath the tips of the fibers.

16. A combination according to claim 15 wherein the substrate is an adhesive.

17. A combination according to claim 15 wherein said fibers comprise one of the following carbon, graphite, metal, ceramic and diamond.

18. A combination according to claim 15 wherein the fibers comprise carbon fibers.

19. A combination according to claim 15 wherein said assembly comprises a semiconductor package that includes said heat sink, semiconductor die and interface.

20. A combination according to claim 15 wherein said encapsulant comprises gels, such as silicone gels, and spray gasket materials.

21. A method of making a semiconductor assembly comprising:

a) providing thermally conductive fibers of desired length;

b) applying adhesive to a substrate;

c) flocking the fibers to the substrate and embedding said fibers into the adhesive with a portion of the fibers extending out of the adhesive;

d) curing the adhesive;

e) disposing a curable encapsulant between fibers extending out of the adhesive and beneath the free tips of the fibers;

f) compressing the fibers with encapsulant between the fibers into the adhesive to less than the nominal fiber length and clamp to the compressed height;

g) curing the encapsulant while under compression to yield a free fiber tip structure with fiber tips extending out of the adhesive; and

h) interposing the free fiber tip structure between a semiconductor die and a substrate.

22. A method according to claim 21 further comprising interposing a release liner between the uncured encapsulant and fiber prior to curing the encapsulant.

23. A method according to claim 21 wherein in step (g) said encapsulant in step (d) is cured under compression during step (g).

24. A method according to claim 21 wherein the fibers comprise one of carbon fibers, graphite fibers, metal fibers, ceramic fibers and diamond fibers.

25. A method according to claim 21 wherein the fibers are electroflocked to the substrate.

26. A method according to claim 21 wherein the fibers are pneumatically flocked to the substrate.

27. A method according to claim 21 wherein the fibers are mechanically flocked to the substrate.

28. A method of making a semiconductor assembly comprising a semiconductor package having a lid, a semiconductor die disposed in the package and a heat sink comprising:

a) providing thermally conductive fibers of desired length;

b) applying adhesive to a substrate;

c) flocking the fibers to the substrate and embedding the fibers at one end into the adhesive with tips of the fibers extending out of the adhesive;

d) curing the adhesive;

e) filling space between fibers extending out of the adhesive and beneath the tips of the fibers with a curable encapsulant;

f) compressing the fibers in the adhesive with encapsulant in the spaces between the fibers into the adhesive to less than the nominal fiber length and clamp to the compressed height;

g) curing the encapsulant to yield a free fiber tip structure with fiber tips extending out of the adhesive; and

h) interposing the free fiber tip structure between a semiconductor die and the lid.

29. A method according to claim 28 further comprising interposing a release liner between uncured encapsulant and fiber prior to curing the encapsulant.

30. A method according to claim 28 wherein the fibers are electroflocked to the substrate.

31. A method according to claim 28 wherein the fibers are pneumatically flocked to the substrate.

32. A method according to claim 28 wherein the fibers are mechanically flocked to the substrate.

33. A semiconductor assembly according to claim 28 wherein the fibers comprise one of carbon fibers, graphite fibers, metal fibers, ceramic fibers and diamond fibers.

34. A method of making a semiconductor assembly comprising a semiconductor package having a lid and a semiconductor die disposed in the package comprising:

a) providing thermally conductive fibers of desired length;

b) applying adhesive to a substrate;

c) flocking the fibers to the substrate and embedding the fibers at one end into the adhesive with tips of the fibers extending out of the adhesive;

d) curing the adhesive;

e) filling space between fibers extending out of the adhesive beneath the tips of the fibers with a curable encapsulant;

f) compressing the fibers in the adhesive with encapsulant between the fibers to less than the nominal fiber length and clamp to the compressed height;

g) curing the encapsulant to yield a free fiber tip structure with fiber tips extending out of the adhesive; and

h) interposing the free fiber tip structure between a semiconductor die and the lid and between the lid and the heat sink.

35. A method according to claim 34 further comprising interposing a release liner between uncured encapsulant and fiber prior to curing the encapsulant.

36. A method according to claim 34 wherein the fibers are electroflocked to the substrate.

37. A method according to claim 34 wherein the fibers are pneumatically flocked to the substrate.

38. A method according to claim 34 wherein the fibers comprise one of carbon fibers, graphite fibers, metal fibers, ceramic fibers, and diamond fibers.

39. A method according to claim 34 wherein in step (g) said encapsulant is cured under compression.

40. A method according to claim 34 wherein the fibers are mechanically flocked to the substrate.

41. A method according to claims 21, 28 and 34 wherein the adhesive and encapsulant are cured substantially simultaneously.

42. A combination for use in a semiconductor assembly comprising a package containing a semiconductor die, a heat sink device and an interface between the package and heat sink device, said interface comprising a free fiber tip structure comprising flocked thermally conductive fibers embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive, and encapsulant disposed between the portions of the fibers that extend out of the adhesive and beneath the free tips of the fibers.

43. A combination for use in a semiconductor assembly comprising a lid, and an interface comprising a free fiber tip structure, said free fiber tip structure comprising flocked thermally conductive fibers embedded in a substrate in substantially vertical orientation with portions of the fibers extending out of the substrate and encapsulant disposed between the portions of the fibers that extend out of the substrate and beneath the tips of the fibers.

44. A combination comprising a heat spreader and an interface comprising a free fiber tip structure, said free fiber tip structure comprising flocked thermally conductive fibers embedded in a substrate in substantially vertical orientation with portions of the fibers extending out of the substrate and encapsulant disposed between the portions of the fibers that extend out of the substrate and beneath the tips of the fibers.

45. An interface comprising a free fiber tip structure adapted for use in a semiconductor assembly, said free fiber tip structure comprising flocked thermally conductive fibers embedded in a substrate in substantially vertical orientation with portions of the fibers extending out of the substrate and encapsulant disposed between the portions of the fibers that extend out of the substrate and beneath the tips of the fibers.

FIG. 1

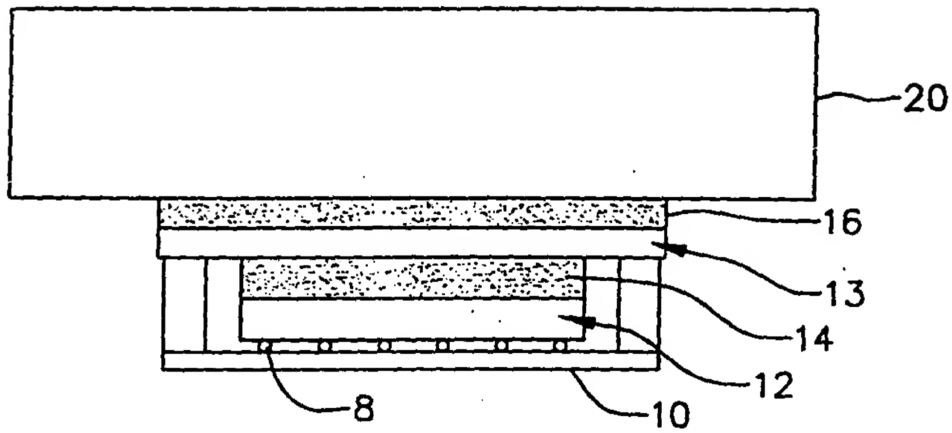

FIG.2C

FIG.2B

FIG.2A

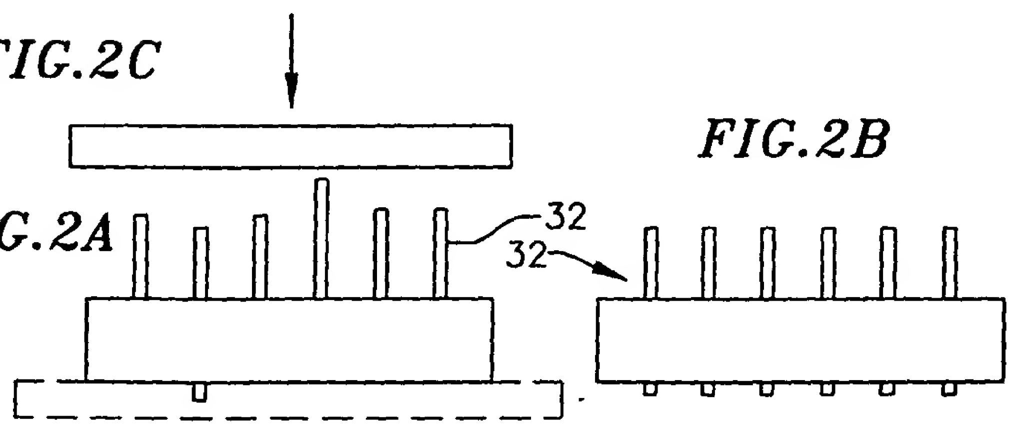

FIG. 3